

EAS data at the mountain level and a shape of the CR spectrum beyond the break.

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Abstract. In the most works which deal with EAS the CR energy spectrum is deduced by means of the model defined dependence $E_0 = a \cdot N_e^\alpha$. An electron total number N_e is evaluated by integration of the NKG-function $f(r)$. This algorithm breaks down for young EAS with age parameter $s \sim 0$. This work shows, that part of the young EAS becomes large in the range $N_e \geq 10^7$, it cause to divergency of the N_e integral for them and distorts the shape of EAS (CR) spectrum. A final analysis of the experimental data permits to conclude that EAS spectrum has local maximum at $N_e \sim 10^9$, which results in a decrease of the EAS spectrum slope for $N_e \geq 10^7$ (inverse break or “knee”). A local maximum can arise because of the additional CR component in the range $E_0 \geq 10$ PeV.

1 Introduction

A total electron number N_e spectrum is analyzed for EAS (extensive air showers), detected at Tien Shan altitude (685 g/cm²) in experiment “Hadron” (Abdrashitov et al., 1986, @). The range under study $N_e = 10^6 - 10^9$ involves EAS spectra break at $N_e \simeq 1.5 \cdot 10^6$ and the main aim of this work is to investigate the spectrum shape beyond the break.

A peculiarity in EAS spectrum is often named as “knee”, implying that an inverse changing of EAS spectrum slope is observed beyond the break. A value of this changing is differ in the dissimilar experiments, i.e. depends of the detecting level, installation design, in particular the kind of detectors and them separation, and methods of N_e estimation.

It will be shown that a peculiarity vary in shape to comparison with one, received in (Nesterova et al., 1995, @), if N_e dependence of the EAS age parameter s is taken into account. A considerable increase of the young EAS part with a small s can decreases the EAS intensity for a large N_e , that cause to maximum formation in EAS spectrum at $N_e \sim 10^8$.

2 Experimental results and methodic.

The total electron number N_e as usual is determined by integral:

$$N_e = 2\pi \int_0^\infty f_{NKG}(r, \hat{s}) r dr, \quad (1)$$

where r is a distance from EAS axis and

$$f_{NKG}(r) = C(s) \cdot \left(\frac{r}{r_m}\right)^{s-2.0} \cdot \left(1 - \frac{r}{r_m}\right)^{s-4.5}, \quad (2)$$

is NKG (Nishimura-Kamata-Greysen) functions, r_m - Molier radius and a normalized coefficient

$$C(s) = \frac{1}{2\pi} \frac{\Gamma(4.5 - s)}{\Gamma(s)\Gamma(4.5 - 2s)} \simeq 0.366 s^2 (2.07 - s)^{1.25}. \quad (3)$$

LDF (lateral distribution function) is defined by the follow expression:

$$\rho_{e^-} = \frac{N_e}{r_m^2} f_{NKG} \quad (4)$$

In a frame of this approximation the values of the individual NKG-function are determined by an estimation of the parameter $s = \hat{s}$ (LDF slope) and a normalization to a sum of the experimental e^- densities ρ_i in the scintillator detectors.

An algorithm for N_e estimation cited above is true for EAS with s -parameter ~ 1 or more, but it breaks down at $s \rightarrow 0$, as $f_{NKG} \sim 1/r^2$ in that case and an integral in Eq. (1) is diverged. A pole in $s = 0$ isn't a physical one and to get rid of the divergency one must introduce a cut-off for the $f_{NKG}(r)$ in area close to $r \sim 0$. N_e is defined by the numerical integration in that case (Shaulov, 1996, @). A cut-off radius is selected of order $r_0 \sim 0.5 - 1$ m.

As usual EAS part with $s \sim 0$ is negligible but it increases with N_e in particular beyond the break for $N_e \geq 5 \cdot 10^6$ (Cherdyntceva et al., 1999, @).

An all EAS spectrum is compared with one's for the most young EAS with $s < 0.4$ and the most old with $s > 1.2$. The

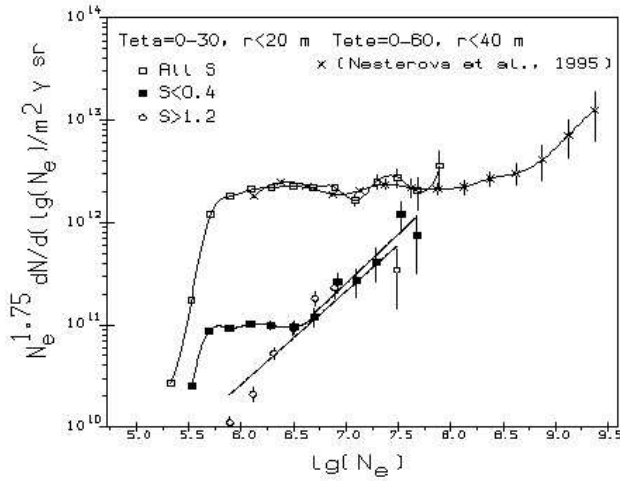


Fig. 1. N_e spectra, multiplied by $N_e^{1.75}$, for all EAS, young EAS with small s -parameter $s < 0.4$ and old EAS with $s > 1.2$. EAS spectrum from (Nesterova et al., 1995, @) is marked by skewed crosses.

spectra are multiplied by $N_e^{1.75}$. At the left of Figure everything spectra are limited by the EAS detecting threshold.

A s -parameter distribution is changed above the break, as EAS part with $s < 0.4$ increases from $\sim 5\%$ for $N_e \sim 3 \cdot 10^6$ up to $\sim 40\%$ for $N_e \sim 3 \cdot 10^7$. At the same range the part of old EAS is increased too and it is worthy to empathize that their part for small N_e is negligible. The last circumstance explains an increase of the s -parameter average value \bar{s} for $N_e > 10^7$ (Cherdyntceva et al., 1999, @).

A EAS spectrum from (Nesterova et al., 1995, @) is shown in Fig. 1 too. It was received with much more EAS statistic by means of increase the selection radius from $r \leq 20$ m up to $r \leq 40$ m and range zenith angles up to $\theta \leq 60^\circ$. Attention is drawn to the fact that an EAS intensity increase for $N_e > 10^8$ may be connected with young EAS to a large degree.

NKG cut-off in range $r < 1$ m for EAS with $s < 0.4$ decreases the average value N_e and changes the spectrum shape. The resulting CR energy spectrum is shown in Fig. 2 in comparison with AGASA one (Takeda et al., 1998, @). A conversion from N_e to energy was made in response to quasi-scaling model (Erlykin, 1986, @) by means of expression $E = 15.1 \cdot N_e^{0.84}$ PeV.

NKG limitation near the EAS axis decreases N_e and causes to maximum formation at energy $E \sim 5 \cdot 10^{16}$ eV. In addition the intensities of the two spectra (Tien Shan and AGASA) were brought into coincidence in the intermediate area. Furthermore a resemblance between these parts of CR spectra in the ranges $E = 3 \cdot 10^{15} - 3 \cdot 10^{17}$ eV and $E = 3 \cdot 10^{18} - 3 \cdot 10^{20}$ eV can be discussed.

3 Discussion

A true reconstruction of the original shape for CR spectrum is of the utmost significance for the “knee” interpretation.

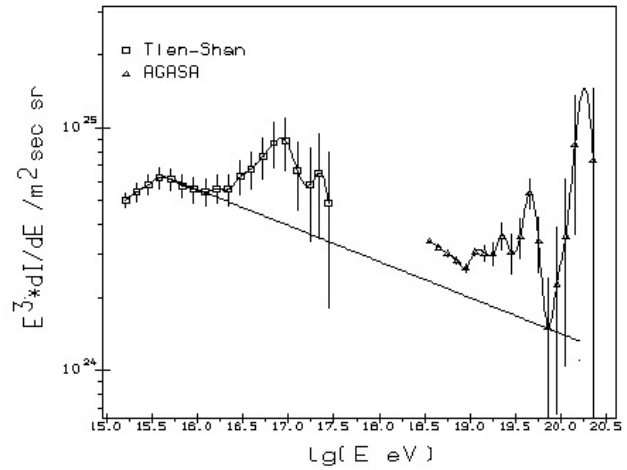


Fig. 2. CR energy spectrum, derived from Tien Shan and AGASA EAS data. Spectrum is multiplied by E^3 .

Initially the “knee” model was based on two assumptions: i) a break in the CR nuclear spectra occurs at a value of the magnetic rigidity $R \simeq 3 - 4$ PV, ii) protons are the dominant CR component ($\sim 40\%$) up to energies in few PeV. A very simple “knee” explanation results in this case. A break in CR spectrum is connected with one in protons component and “knee” is formed by more heavier nuclei.

This model breaks down if the experimental results, which were received in succeeding years, are taken into account.

The direct measurements (Grigorov et al., 1970, @; Burnett et al., 1983, @; Burnett et al., 1995, @) have shown that protons part isn't exceed 25% even at energies in hundreds TeV and continues to decrease up to the break in accordance with EAS data (Chatelet et al., 1991, @). It was confirmed by investigation of the N_e spectrum for EAS with γ -families in experiment “Hadron”, in which a small value of the magnetic rigidity for break in nuclear spectra was received $R \simeq 0.1$ PV (Shaulov, 1999, @).

A model with break for $R \simeq 0.1$ PV only can't be true, because it gives too heavy CR composition for high energies. It seems that a situation is saved by another experiment “Hadron” result about arising of the additional component in CR, consisting mainly from protons, beyond the CR spectrum break (Shaulov, 2001, @). The data of this work about EAS spectrum shape agree well with such conclusion.

It means that transformed “knee” model consists from break in nuclear spectra for the magnetic rigidity $R \simeq 0.1$ PV and a contribution of the additional CR component in the radiation for energies $E \geq 5 - 10$ PeV.

The absence of this maximum or them more small value in CR spectrum ($E \sim 5 \cdot 10^{16}$ eV) for the measurements at sea level may be explained by the large separation between detectors in the installation with large square, that can cause to the loss of the most young EAS, or the difference of this component absorption in the atmosphere in comparison with nuclei one's.

Acknowledgements. I am thanks all experiment “Hadron” partici-

pants, which heavy-duty operation permits to receive these experimental data.

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